Neoclassical Convergence Versus Technological Catch-Up: A Contribution for Reaching a Consensus

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Abstract

New macro empirical evidence is provided to assess the relative importance of object and idea gaps in explaining the world income distribution dynamics. Formal statistical hypothesis tests allow us to discriminate between two competing growth models: (i) the standard neoclassical growth model similar to that employed by Mankiw, Romer, and Weil (1992), (ii) an extension of the Nelson and Phelps' approach (1966) that emphasizes the importance of technology transfer in addition to factors accumulation. First, the latter model better characterizes international data at an aggregate level. It cannot be rejected as a null hypothesis and is significantly preferred to a standard neoclassical model. Second, robust to sample selection evidence suggests that the high social returns to investment in equipment (as opposed to structure) reflect technology transfer mediated through capital goods. Finally, technological catch-up mostly benefits "socially" advanced economies and largely contributes to the polarization of the world income distribution.

Keywords: economic growth, neoclassical convergence, technological catch-up, and income dynamics.

JEL Classification: C12-C14-C21-O33-O40-O50

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"We could produce statistical evidence that all growth came from capital accumulation, with no room for anything called technological change. But we could not believe it."

Romer (1993; p. 562)

1. Introduction

In the neoclassical theory, even though the assumption of a common rate of technological progress across a worldwide set of countries is hardly defensible, technology is assumed to be a pure public good that is available to everyone everywhere free of charge. In contrast, an alternative view suggests that poorer countries may suffer from a technological gap. This requires technology to be considered less public. Total factor productivity growth may thus differ across countries, at least for a transitional period, depending, for instance, on both the technological gap and the absorption capacity of a nation. Both approaches may exhibit an opportunity for countries lagging behind to catch up, though for different reasons. In the neoclassical theory, poorer countries may converge to rich ones because there are diminishing returns to capital. In the technology-gap approach, a high absorption capability makes it easier for a poor country to catch up because of the opportunity for faster growth through technology adoption and implementation.

Because both approaches are not mutually exclusive, I investigate within a unified theoretical and empirical framework the relative importance of both these phenomena at an aggregate level. The first alternative has been empirically investigated in a seminal contribution by Mankiw, Romer, and Weil [14] who are able to account, within a cross-country growth regression explicitly derived from a neoclassical growth model, for 46% of the observed dispersion of growth rates across countries over the post World War II period. They consider a human capital augmented version of the Solow [21] growth model and conclude that (p. 433): "...our results indicate that the Solow model is consistent with the international evidence if one acknowledges the importance of [the accumulation of] human as well as physical capital." In particular, there is conditional convergence in the sense that lower initial values of output per worker generate higher transitional growth rates, once the determinants of the steady state are controlled for.

Nelson and Phelps [16] provide an early example of a formal model that incorporates the idea that a country may benefit from its technological backwardness depending on its absorption capability that can be approximated by its stock of human capital. They suggest that the growth of total factor productivity is a function both of the level of human capital and the technological gap because an educated labor force is expected to be better at adopting foreign technologies, thereby generating growth (see also Abramowitz [1] for a more recent but less formal contribution to this line of research). Benhabib and Spiegel [4] take seriously this alternative and provide an interesting empirical criticism of Mankiw, Romer, and Weil's conclusions. Within a growth accounting exercise, they find that growth remains essentially uncorrelated with educational achievement when one considers an augmented Solow model where human capital is nothing but an ordinary input in the aggregate production function, but educational attainment levels become significantly correlated with growth when one assumes as in Nelson and Phelps that the stock of human capital positively affects the rate of diffusion of the existing technology[1].

To assess the relative importance of the opportunity to catch up because of diminishing returns to reproducible factors as in a neoclassical framework and the opportunity to catch up because of differences in technology, I present a simple growth model characterized by a neoclassical production function that exhibits constant returns to scale and where education speeds up technological diffusion through the economy as in Nelson and Phelps. Following De la Fuente [6] , I then explicitly derive and estimate a convergence equation whose fit and specification which incorporates both the neoclassical convergence effect and the technological catch-up effect, can be compared to the empirical results found by Mankiw, Romer, and Weil. In particular, specification statistical testing allows us to choose among the two competing models. Proceeding this way, also allows us to analyze within an unified empirical framework, one which has already been shown to have some success[2], whether traditional inputs and/or productivity are important in explaining international growth differences. Finally, Fagerberg [11] , in an insightful survey on technology and international growth differences, emphasizes a key finding of an influential article by De Long and Summers [8] . These two authors suggest that their high estimated social returns to investment in equipment (as opposed to structures) may

[1] Both these empirical studies also raise another crucial economic issue. Is growth primarily driven by the accumulation of human capital as in Mankiw, Romer, and Weil, or are differences in growth rates primarily due to differences in human capital stocks that act as a factor constituting a country's ability to engage in technological progress? Aghion and Howitt [2] emphasize how important it is to distinguish between these two frameworks because they deliver different insights as to the growth effects of various educational policies.

[2] Traditionally, researchers that focus on productivity adopt an approach based on growth accounting. In order for my results to be directly comparable to the seminal Mankiw, Romer, and Weil's contribution, I voluntarily choose to use their approach, that is, one of estimation.

to some extent reflect technology transfer mediated through capital goods. The share of equipment in output may be important in explaining growth in total factor productivity. It is, therefore, also used in the statistical analysis as a proxy of the absorption capability of a nation.

Romer [18] stresses how important it is to assess the relative importance of what he calls “object gaps” versus “idea gaps” because each imparts a distinctive thrust to the analysis of economic development. Even though his notion of idea gap is quite wider than the notion of technological gap invoked here, this article aims precisely at providing new evidence about the relative importance of ideas versus objects in international growth differences[3]. It makes use of a formal model and statistical hypothesis testing that allow us to fully appreciate whether data is consistent with the view that there are only object gaps as in an augmented human capital Solow model, or with the view that both idea gaps and object gaps are important to explain the world income dynamics.

This article is organized as follows. In Section 2, I present a descriptive growth model that allows for both the neoclassical convergence effect and the technological catch-up effect, and explicitly derive a convergence equation from it. In Section 3, I estimate the model and compare it to a Mankiw, Romer, and Weil’s specification by associating with each model estimated loss functions. Nonnested specification tests also allow us to discriminate between the two rival models. A key finding is that the Mankiw, Romer, and Weil’s specification should be either discarded or improved as compared to a Nelson and Phelps’ specification when the absorption capability of a country is approximated by its share of equipment investment in output and interacts with its backwardness to affect the level of productivity. Robust to sample selection macro empirical evidence strongly suggests the importance of technology transfer mediated through capital goods as suggested, for instance, by De Long and Summers [8] . When the absorption capability is proxied by the stock of education at tertiary levels, the Mankiw, Romer, and Weil’s specification is also rejected as a null hypothesis against a nested version of the Nelson and Phelps’ specification when I consider a “non oil” and an “intermediate” sample of countries, and the OECD group. With stocks of human capital at secondary levels, both models appear to well characterize the data for a world wide set of countries, though a preference may be given to the Nelson and

[3] Romer’s notion of object gap highlights saving and accumulation as emphasized, for instance, by Mankiw, Romer, and Weil, while his notion of idea gaps directs attention to the patterns of interaction and communication between nations. This notion of idea gaps encompasses both the social absorption and the technology gap concepts introduced by Nelson and Phelps in their formal model.

Phelps' approach given the probabilities to commit a first error type. As for education at tertiary levels, the Nelson and Phelps' model is preferred when applied to the OECD sample. Finally, in Section 4, counterfactual income density estimates provide a visually clear representation of where in the density of incomes the different convergence effects exert the greatest impact over the period under study. Although the neoclassical convergence effect affects uniformly the world income distribution, the technological catch-up has important non linear effects on the evolution of the income distribution. In particular, it yields the middle-income group of countries to vanish. It appears to be a key factor that is, at least partially, responsible for the polarization of the world income distribution that has been highlighted by Quah [17] . This corroborates, among others, Abramowitz who argues that only those poorer countries that benefit from a high absorption "social capability" will be able to catch up. Section 5 concludes and discusses some implications of these empirical results.

2. A Growth Model with Factor's Accumulation and Technological Diffusion

In this section, I develop a simple growth model and explicitly derive a conditional convergence equation where education speeds up technological diffusion throughout the economy as in the partial Nelson and Phelps' model. I closely follow the descriptive growth model proposed by De la Fuente.

Let us start from an aggregate Cobb-Douglas production function exhibiting constant returns in labor and reproducible capital as in Mankiw, Romer, and Weil of the form

$$Y(t) = K(t)^{\alpha}(A(t)L(t))^{1-\alpha} \tag{1}$$

where A is an index of labor-augmenting technological progress. K denotes a broad physical capital aggregate[4], and L the labor force such that $L(t) = L(0)e^{nt}$, with n an exogenous constant growth rate of the labor force. Define k as the stock of capital per unit of effective labor, then output per worker is

[4] K may be interpreted as a capital aggregate that includes both human and physical capital as in the augmented human capital Solow model proposed by Mankiw, Romer, and Weil.

$$y(t) = A(t)k(t)^{\alpha} \tag{2}$$

Growth of output per worker is therefore the result of the accumulation of the productive inputs or the outcome of technological progress. Taking logarithms of (2) and differentiating with respect to time, the rate of growth of output per worker can be written as the sum of two terms that reflect, respectively, growth in total factor productivity and the accumulation of reproducible factors

$$\frac{\dot{y(t)}}{y(t)} = d\left[\log(y(t))\right]/dt = \gamma_y(t) = \gamma_A(t) + \alpha\gamma_k(t) \tag{3}$$

The problem consists in specifying the immediate determinants of γ_A and γ_k. Let us start with the second factor. The evolution of physical capital is given by

$$\gamma_k(t) = sk(t)^{\alpha-1} - (n + \gamma_A(t) + \delta) \tag{4}$$

where s is a constant fraction of gross income invested in physical capital and δ the rate of depreciation.

With $\alpha \in \,]0,1[$, the behavior of the dynamical system described by (4) is such that the system is stable, and the stock of capital per unit of effective labor converges to its stationary value k^*, characterized by

$$\gamma_k(t) = 0 \Rightarrow k^* = \left(\frac{s}{n + \gamma_A + \delta}\right)^{1/1-\alpha} \tag{5}$$

The implications of this result for convergence are now well-known. Two economies with the same values of the parameters, s, n, and δ, and that have access to the same technology but that differ in their initial capital stocks will converge to a similar stock of capital per unit of effective labor. This is the neoclassical convergence effect which results from the diminishing returns in reproducible factors' assumption.

I now specify the determinants of the rate of technological progress as in Nelson and Phelps, where the rate of technological progress is driven by the stock of human capital, which in turn affects a country's ability to catch up with more advanced economies. Define a technological distance between $A(t)$ and the best-practice level of technology

$T(t)$, that would prevail if technological diffusion were completely instantaneous. $T(t)$ expands at a strictly positive exogenous constant rate, g. Improved technological practice is assumed to depend upon educational attainment and upon the gap between the theoretical level of technology and the level of technology in practice. More specifically

$$\gamma_A(t) = \Phi(h) \log \left(\frac{T(t)}{A(t)} \right) \text{ with } \Phi(0) = 0, \text{ and } \Phi'(h) > 0 \tag{6}$$

Note first that, in the long run, if h is positive, the rate of increase of the level of technology in practice settles down to the value g, independently of the index of educational attainment. Thus, education influences the growth of total factor productivity only in the short run. Second, in a stagnant economy ($g = 0$), the gap, defined as $b(t) = \log(T(t)/A(t))$, approaches zero for every $h > 0$. Finally, there is a positive equilibrium gap ($b^*(t) = \log(T(t)/A^*(t))$) for every g and h where,

$$\frac{db(t)}{dt} = 0 \Rightarrow \gamma_{A^*} = g \text{ and } b^* = \frac{g}{\Phi(h)} \tag{7}$$

The equilibrium gap is an increasing function of g and a decreasing function of the index of educational attainment.

Substituting (6) into (4) leads

$$\gamma_k(t) = sk(t)^{\alpha-1} - (n + \Phi(h)b(t) + \delta) \tag{8}$$

The transitional dynamics can be quantified by using a log linear approximation of (8) around the steady state. The solution for $\log(k(t))$ given the above Cobb-Douglas technology is

$$\gamma_k(t) \simeq -\beta\widetilde{k}(t) - \Phi(h)\widetilde{b}(t) \tag{9}$$

with $\beta = (1-\alpha)(n+g+\delta)$ that determines the speed of convergence from $k(t)$ to k^*. $\widetilde{k}(t)$, respectively $\widetilde{b}(t)$, is equal to $\log(k(t)/k^*)$, respectively $b(t) - b^*$, and denotes the deviation of the stock of capital per unit of effective labor, respectively of the technological gap, from its steady state value.

Given (2), (3), and (9) we have[5]

$$\gamma_y(t) \simeq \gamma_A(t) - \beta(\log(y(t)) - \log(A(t))) + \alpha(\beta \log(k^*) - \Phi(h)\widetilde{b}(t)) \tag{10}$$

It remains to incorporate in (10) the behavior of the technological variable. Note that $db(t)/dt = g - \Phi(h)b(t)$, the time path of $b(t)$ is given by

$$b(t) = b(0)e^{-\Phi(h)t} + b^*(1 - e^{-\Phi(h)t}) \text{ or } \widetilde{b}(t) = \widetilde{b}(0)e^{-\Phi(h)t} \tag{11}$$

Substituting (11) into (6) and using (7), the rate of technological progress at time s is given by

$$\gamma_A(s) = \Phi(h)b(s) = \Phi(h)\left[b(0)e^{-\Phi(h)s} + \frac{g}{\Phi(h)}(1 - e^{-\Phi(h)s})\right] = \Phi(h)\left[\widetilde{b}(0)e^{-\Phi(h)t}\right] + g \tag{12}$$

Integrating (12) from 0 to t, we obtain the time path of the logarithm of the productivity index

$$\log(A(t)) = \log(A(0)) + gt + \widetilde{b}(0)(1 - e^{-\Phi(h)t}) \tag{13}$$

Substituting now (11), (12), and (13) into (10) leads to the following convergence equation

$$\begin{aligned} \gamma_y(t) \quad \simeq \quad & \Phi(h)\left[\widetilde{b}(0)e^{-\Phi(h)t}\right] + g - \beta\left[\log(y(t))\right] + \beta\left[\log(A(0)) + gt + \widetilde{b}(0)(1 - e^{-\Phi(h)t})\right] \\ & + \alpha\beta\log(k^*) - \alpha\Phi(h)\widetilde{b}(0)e^{-\Phi(h)t} + \beta\log(T(0)) - \beta\log(T(0)) \end{aligned} \tag{14}$$

Note that $\widetilde{b}(0) = b(0) - b^* = \log(T(0)/A(0)) - g/\Phi(h)$. If we define $\eta \equiv \Phi(h)/(n + g + \delta)$, then (14) can be rewritten

$$\begin{aligned} \gamma_y(t) \quad \simeq \quad & g + \beta\log(T(0)) + \beta gt - \beta\log(y(t)) + \frac{\alpha\beta}{(1-\alpha)}\log s - \frac{\alpha\beta}{(1-\alpha)}\log(n + g + \delta) \\ & - \beta\frac{g}{\Phi(h)} + \beta\left[\log\left(\frac{T(0)}{A(0)}\right) - \frac{g}{\Phi(h)}\right](\eta - 1)e^{-\Phi(h)t} \end{aligned} \tag{15}$$

[5] and it becomes now clear that asymptotically the technological gap of a given country converges in the long run to a constant value $b^* = g/\Phi(h)$.

Following Barro and Sala-i-Martin [3] and Mankiw, Romer, and Weil, the model predicts conditional convergence. Across a set of economies that approach the same steady state, poor countries should grow faster on average than rich countries because of diminishing returns to capital accumulation. Following the traditional conditional convergence literature, the growth rate of output per worker is an increasing function of investment in physical capital and decreases with the log of the contemporaneous level of income, and with the growth rate of the labor force. However, in contrast to the previous literature, education does not enter as another ordinary factor of production that affects growth through its rate of accumulation[6].

Instead, equation (15) is consistent with the Schumpeterian approach and suggests that human capital drives growth by affecting a country's ability to catch up with more advanced countries. Another important reason why convergence should occur in this model is technology diffusion whose speed depends on the available stock of human capital. The larger the technological gap the faster the backward countries' growth rate is once one controls for differences in factors' accumulation as well as differences in the absorption capability. The stock of human capital influences growth during transition in two specific ways. On the one hand, the growth of output per worker is a decreasing function of the equilibrium gap that is itself a decreasing function of the stock of human capital. On the other hand, for a given stock of human capital, the growth rate of output per worker increases with the deviation of the initial technological gap from the equilibrium gap. Recall that $\eta \equiv \Phi(h)/(n+g+\delta)$, the higher the available stock of human capital, the more an economy is able to adapt and implement technologies developed elsewhere. However, the contribution of the catch-up process also decreases with time as its productivity level converges towards the technological frontier and the rate at which it converges to zero also depends positively on the stock of human capital.

Differences in education are therefore important to explain differences in growth rates. However, in contrast to the Mankiw, Romer, and Weil's approach, growth is not driven by the accumulation of human capital, where differences in the rates at which countries accumulate can explain why growth rates differ. Instead, growth is driven by the stock of human capital, which in turn affects a country's ability to absorb new technologies and therefore to catch up. In

[6] It would be straightforward to consider a nested model where human capital enters as an input in the production function as in Mankiw, Romer, and Weil who rather specify the following production function: $Y(t) = K(t)^{\alpha} H(t)^{\beta} (A(t)L(t))^{1-\alpha-\beta}$. This more general model is estimated and discussed in the following section.

other words, the world is not composed of economies that all benefit from the state of the art of technology which is considered in a neoclassical framework as a pure public good, but of economies that do not have access to the same level of technology, and that may benefit from their lagging behind according to their absorption capability as proxied by their stock of human capital.

3. Growth Regressions

3.1 Data and Specification

To investigate the relative importance of the technological catch-up process and of the neoclassical convergence effect as proposed in the above model, I use data from Mankiw, Romer, and Weil [14] , and data constructed by Nehru, Swanson, and Dubey [15] . The data from Mankiw, Romer, and Weil will be used in a benchmark regression, to compare the above model where human capital enhances an economy's ability to adapt and implement new technologies, and the Mankiw, Romer, and Weil's human capital augmented version of the Solow model.

The stock of human capital is approximated by using recent series of estimates of the stock of education provided by Nehru et Al. who proxy human capital by the accumulated years of schooling present in the working age population. These series are built from enrollment data using the perpetual inventory method adjusted for mortality. The stock of human capital at time t is therefore, built up from past investments in schooling. Although these estimates were built to calculate total factor productivity growth for a wide range of economies, I propose here to use them in traditional growth regressions as suggested by the above model[7].

Three aspects of the choice of variables deserve some discussions. First, Nehru et Al. provide education stocks for 73 countries that intersect with the original Mankiw, Romer, and Weil's "non-oil" sample of developing and industrialized countries and with the De long and Summers [9] data on equipment investment. The human capital stocks data available in Benhabib and Spiegel [4] covers a smaller number of countries. Second, following Benhabib and Spiegel, the technological catch-up effect is captured via an interactive term that involves the average education stock

[7] Note that I will consider the education stocks built up from both the secondary and tertiary enrollments. If, as suggested by the above model, more human capital facilitates the absorption of foreign technology, it is likely to be especially important for education at the secondary and tertiary levels.

over the period (H) and the gap of a country behind the leader at the beginning of the period in terms of the level of initial output per working-age person ($\ln(Y60_{\max}/Y60)$). This specification also follows Barro and Sala-i-Martin who acknowledge in their conclusion the possibility that the convergence observed from the estimation of a convergence equation similar to that of Mankiw, Romer, and Weil should be broken down into at least two components, reflecting both diminishing returns to capital and effects that involve the spread of technology[8]. Abramowitz also emphasizes the importance of such an interaction term suggesting that a country's potential for rapid growth will be strong only if it is technologically backward but socially advanced where education can be seen as a good proxy of the absorbing capability of a country. Finally, the stock of human capital also acts independently of any other variables in the convergence equation (15) because it also determines the equilibrium technological gap that also influences contemporaneous growth. It is therefore, also introduced in the growth regression estimated below though we can expect that it will contribute to the emergence of collinearity problems[9]. More specifically, I specify the following convergence equation:

$$Growth_i^{60-85} = c+\beta_1 \ln(Y60)_i+\beta_2 \ln(I/GDP)_i+\beta_3 \ln(n_i+g+\delta)+\beta_4 H_i+\beta_5 (H_i . \ln(Y60_{\max}/Y60)_i+\epsilon_i \quad (16)$$

where ϵ_i is a normally distributed error term reflecting a country-specific shock. The dependent variable is the log difference of output per working-age person over the period. $Y60$ is GDP per working-age person in 1960. The shares of real investment in real GDP and population growth rates are averages for the period 1960-1985. $(g+\delta)$ is assumed to be equal to 0.05 as in Mankiw, Romer, and Weil. All these variables are borrowed from the Mankiw, Romer, and Weil data set except the average stock of human capital over the period that is issued by the Nehru et Al. data set. Results obtained with the estimation of equation (16) can therefore be directly compared to results obtained with a Mankiw, Romer, and Weil specification where the rate of accumulation of human capital is proxied by the average percentage

[8] Much of the technological catch-up literature also includes per worker output as a proxy for the scope for catch-up. (See for instance, the insightful survey on technology and growth by Fagerberg.) The choice of this proxy must be seen as a good point from which to start to assess the relative importance of object and idea gaps at an aggregate level if output per worker is highly correlated with the level of technological development.

[9] Note the similarity with equation (15) and the following structural specification of total factor productivity growth estimated by Benhabib and Spiegel

$[\log A_T(H_t) - \log A_0(H_t)]_i = c + gH_i + mH_i[(Y_{\max} - Y_i)/Y_i]$

where c represents exogenous technological progress, gH_i represents endogenous technological progress associated with the ability of a country to innovate domestically, and $mH_i[(Y_{\max} - Y_i)/Y_i]$ represents the diffusion of technology from abroad.

of the working-age population in secondary school for the period 1960-1985 ($SCHOOL$). The goal is to see whether the technological catch-up effect as specified in equation (16) allows us to make progress in explaining the evolution of the world income distribution and to solve the problem of how to map data on educational attainment into growth models.

3.2 Empirical Results

3.2.1 Rates of Accumulation Versus Levels of Human Capital

The results of estimating equation (16) are presented in Table 1 for three samples that intersect with the "non-oil", the "intermediate" and the OECD samples of countries analyzed by Mankiw, Romer, and Weil together with an estimation of their augmented Solow model. I call them the MRW and the NP models. The MRW estimations are used as benchmark regressions that I compare to the regressions obtained with the competing NP model. Although, the MRW model is estimated on a sample of 73 non-oil countries instead of 98 in the original contribution, estimations using these two samples provide similar results. This is equally true for the intermediate and OECD samples.

I first concentrate and analyze results issued by the estimations corresponding to the non-oil sample so that I expect to be able to choose the best model among the two. First, the goodness-of-fit as measured by the adjusted-R^2 and the Akaike information criterion (AIC) that take into account the trade-off between the goodness of fit and the complexity of the models, does not allow us to discriminate between both models. The AIC is slightly smaller in the MRW model (41.4) as compared to the NP model (44.1), but this is because the AIC imposes a greater penalty to increasing the number of independent variables than does the adjusted-R^2.

Note first that, indeed, the NP model is originally specified so that the stock of human capital enters twice in the regression though it is intended to capture only the technological catch-up effect. Second, neither the stock of human capital (H) nor the interaction term ($H.\log(Y60_{\max}/Y60)$) is significantly different from zero. In the absence of multicollinearity, the choice between both models would be obvious. However, the conditional number that measures collinearity is higher in the NP model (4.7) as compared to the MRW model (3.6). Collinearity may, therefore, substantially inflate the variances of the corresponding estimated coefficients. Only one of these two variables should maybe

Dependent variable: log difference GDP per working-age person 1960-1985															
Sample			*Non-oil*					*Intermediate*					*OECD*		
Observations			*73*					*65*					*21*		
[a] Model selection	MRW	[b] SW	NP	SNP	SW	MRW	SW	NP	SNP	SW	MRW	SW	NP	SNP	SW
Constant	2.58		1.98	2.44		3.01		1.71	2.38		3.05		-0.03	0.70	
	[c] (0.00)		(0.07)	(0.00)		(0.00)		(0.11)	(0.00)		(0.02)		(0.98)	(0.00)	
ln(Y60)	-0.27	2	-0.19	-0.13	3	-0.36	2	-0.18	-0.14	3	-0.38	1	-0.05		
	(0.00)		(0.01)	(0.01)		(0.00)		(0.03)	(0.01)		(0.00)		(0.72)		
H2.ln($Y60_{\mathrm{max}}$/Y60)			0.14	0.19	2			0.18	0.22	2			0.27	0.30	1
			(0.12)	(0.00)				(0.07)	(0.00)				(0.03)	(0.00)	
ln(I/GDP)	0.57	1	0.57	0.57	1	0.48	1	0.51	0.52	1	0.28	2	-0.04		
	(0.00)		(0.00)	(0.00)		(0.00)		(0.00)	(0.00)		(0.11)		(0.86)		
ln(n+g+δ)	-0.57	4	-0.34			-0.73	4	-0.37			-0.74	3	-0.40		
	(0.07)		(0.32)			(0.02)		(0.28)			(0.04)		(0.22)		
Ln(School)	0.15	3				0.27	3				0.27	4			
	(0.05)					(0.00)					(0.07)				
H2			0.07					(0.04)					-0.13	-0.16	2
			(0.59)					(0.73)					(0.23)	(0.00)	
d.f.	68		70	69		60		59	61		16		15	18	
s.e.	0.311		0.311	0.306		0.292		0.300	0.294		0.140		0.123	0.119	
$\overline{R}^2$	0.46		0.47	0.48		0.45		0.42	0.45		0.64		0.72	0.74	
[d] κ	3.6		4.7	2.4		3.6		4.5	2.1		1.7		6.3	1.8	
AIC	41.4		44.1	38.3		30.2		34.1	31.9		-18.1		-22.4	-26.7	
[e] LM-test			1.83					1.95					2.42		

Table 1: Tests for neoclassical convergence and technological catch-up where the absorption capability of a nation is approximated by its stock of education at secondary levels.

Notes:

a. MRW corresponds to the Mankiw, Romer, and Weil specification. NP is for Nelson and Phelps and corresponds to the specification as described by equation (16) in the text. SNP corresponds to the model nested within the NP model and selected by the chosen variable selection method. SW is for stepwise procedure as described in the text.

b. In and out order of the variables either added or removed from the model issued by the stepwise procedure.

c. p-values, i.e., the marginal significance level of a two-tailed test of the hypothesis that the coefficient is equal to zero, are in parenthesis under coefficient estimates.

d. κ is the conditional number measuring collinearity.

e. Breusch and Pagan's Lagrange Multiplier test for nested models as described in the text.

be specified in the NP model with loss of information expected to be minimal.

To select a restricted version of this model, a stepwise procedure is applied. The stepwise procedure is a modified forward method. A forward selection procedure starts with no variable in the model and first selects that variable which has the highest correlation with the dependent variable. In a second step, another variable is added that increases the sum of squares more than any other variable. One variable is added at a time until a stopping rule is met. The procedure stops if the F-test for each of the variables not yet entered would be less than some predetermined number, say F_{in}. This method has the disadvantage that it does not eliminate variables that can become nonsignificant after other variables have been added. The stepwise procedure also starts with no independent variable and selects variables one by one to enter the model as in the forward method. But after each new variable is entered, the stepwise procedure examines every variable already in the model to check if it should be deleted, just as in a backward elimination procedure. The backward elimination method is quite similar to a forward method, except that it starts with the full model, and, at each step, removes that variable that has the smallest F value of all the variables in the equation. The procedure stops when the F-test for all the variables left in the model is bigger than some predetermined number, say F_{out}. At each step, the stepwise algorithm therefore considers four alternatives: add a variable, delete a variable, exchange two variables, or stop[10]. In the calculations, the probability F-to-enter (F-to-remove) is set to 0.93 (0.92) to prevent infinite cycles.

It is interesting to notice that the method selects a model (SNP) as described in Table 1 where both the neoclassical convergence effect and the technological catch-up effect as proxied by the interaction term are specified together with the rate of accumulation of physical capital[11]. The SNP model imposes some restrictions on the parameters associated with the NP model. A testing procedure is required to assess whether the SNP model defined as the null hypothesis is indeed nested in the NP model specified in the alternative hypothesis. A Lagrange Multiplier test cannot reject at a 5-percent significance level the selected model as a restricted or specific version of the NP model[12]. The SNP model

[10] It is generally accepted that the stepwise procedure is vastly superior to the other stepwise procedures.

[11] The labor force growth rate does not enter the selected model. This is by now a standard result that the empirical relationship between growth and this variable is not "robust" (see, for instance, Levine and Renelt [13]).

[12] The Lagrange Multiplier test for nested models applied here has been derived by Breusch and Pagan [5] who have shown that for linear hypothesis on linear models, the LM principle involves only two OLS regressions. The test procedure is as follows:

(i) the null hypothesis specifies the selected model (SNP) as a restricted version of that of the alternative hypothesis that specifies the NP (unrestricted) model,

(ii) estimate the residuals from the nested model, is therefore nested within the NP model. The selected model is now characterized by a greater adjusted-R^2 (0.48), a smaller AIC (38.3) and a smaller conditional number (2.4) as compared to the MRW model, solving therefore the problems of collinearity and of degrees of freedom as mentioned above. According to these criteria, the selected model nested within the NP model is to be preferred to the MRW model.

Also interesting is the ordering of the independent variables added in the model by the stepwise method. Recall that when a variable is added, adjusting for the explanatory variables already in the equation, it has the highest sample partial correlation in absolute value with the response variable, it is worth noticing that once the variable reflecting the rate of accumulation of capital is entered, the interaction term is added followed by the initial level of income. None of these variables is removed subsequently. This suggests the relative importance of the technological catch-up effect compared to the neoclassical convergence effect. Finally, the size of the estimated coefficient associated with the neoclassical convergence effect in the selected model lowers by 50 percent compared to its estimated value in the MRW model. Thus, the speed of convergence due to diminishing returns decreases substantially once we control differences in technology as modelled by Nelson and Phelps. Poorer countries may therefore benefit from both diminishing returns to capital and technological gaps once one controls for differences in physical capital accumulation. Hence, there is no reason to reject that differences in technology stand as an important part of the convergence phenomenon that poorer countries may have experienced over the period.

		JA-test		
		Non-oil	*Intermediate*	*OECD*
H0	**H1**			
SNP	MRW	0.34	0.04	0.49
MRW	SNP	0.10	0.23	0.01
		p-value	p-value	p-value

Table 2: Nonnested hypothesis test: MRW versus SNP.

Note: the JA-test performs a test of specification of non nested models as described in the text.

(iii) regress them on the original variables from the model under the alternative hypothesis,

(iv) calculate the statistic NR^2 from this second regression, where N is the number of observations,

(v) compare it with the critical 5 percent value of a χ^2_M where M is the number of constraints implied by the null hypothesis. For $M = 2$ ($M = 3$, $M = 4$), $\chi^2_M = 5.99$ $(7.81, 9.49)$.

If NR^2 is greater than χ^2_M, we reject the null hypothesis with a 5 percent first error type probability, i.e., to reject the null when it is true.

I now turn to testing between the MRW and the selected model that are nonnested models as they are characterized by non-overlapping independent variables. I apply a JA-test that comes about by applying, in a slightly modified form, the Cox principle that generalizes the likelihood ratio procedure used in the case of nested hypothesis. It has the advantage, in contrast, for instance, to the J-test developed by Davidson and MacKinnon [7] , to remain valid for small samples[13]. Results of the test are provided in Table 2. When the selected model is specified as the null hypothesis and the MRW as the alternative hypothesis, it is not rejected. However, this does not mean that it must necessarily be preferred to the MRW model[14]. Once the models are reversed with the previous alternative hypothesis becoming the null, the test tends to reject the MRW model with a much smaller probability of committing a first error type, i.e., to reject it though it is the true model. Given the size of the p-values, 0.34 when the null specifies the selected model against 0.10 when the null specifies the MRW model, we can conclude that the MRW model is rejected with a much smaller probability to be wrong in rejecting it, compared to the probability to be wrong in rejecting the SNP model. In other words, there is no evidence that the SNP model is misspecified. Both models can be accepted and appear to fit satisfactorily the data or at least to equally well characterize them, though the SNP model may be preferred to the MRW model given the one type error probabilities.

I also specify a more general model that incorporates both the MRW model and the NP model. This model is equivalent to an augmented human capital model with a neoclassical production function as in Mankiw, Romer, and Weil but where technological progress is modelled as in Nelson and Phelps. Not surprisingly the conditional number corresponding to this model increases. A stepwise procedure is applied to select a restricted version of it. Again, the investment ratio variable enters first in the model. The interaction term follows and the last variable added is the initial level of income. A LM-test shows that the selected restricted model is again nested within this artificial nesting

[13] The JA-test is a nonnested test derived by Fisher and McAleer [12] . It is based on artificial regressions. The procedure is as follows:
(i) obtain the predictions $\widehat{Y}_i^{(0)}$ of Y_i from the model specified in the null hypothesis,
(ii) obtain the predictions $\widehat{Y}_i^{(0,1)}$ of $\widehat{Y}_i^{(0)}$ from the model specified in the alternative hypothesis,
(iii) augment the model specified in the null hypothesis by the single variable $\widehat{Y}_i^{(0,1)}$, and test the significance of its coefficient.
(iv) The null hypothesis is rejected if the coefficient is significantly different from zero.

[14] Nonnested hypothesis tests do not formulate the hypothesis in a complementary way as in nested hypothesis tests because none of the hypothesis is a particular case of another one. There are therefore four possible outcomes: (i) both models are rejected, (ii) both models are accepted, (iii) the SNP model is accepted and the MRW model is rejected, (iv) the MRW model is accepted and the SNP model is rejected.

model[15].

Estimations for the intermediate sample lead to very similar results. However, the JA-test rejects the selected model nested within the NP model and accepts the MRW model that is also preferred according to the AIC. The opposite is true when one considers the OECD sample. The JA-test accepts the model selected by the stepwise procedure and nested within the NP model and rejects the MRW model. The adjusted-R^2 and the AIC improve substantially[16] when one considers the selected model that now incorporates both the interaction term and the average stock of human capital though with a negative sign for the latter. Note that the selected model does not incorporate anymore the initial level of income. This suggests that among the group of OECD countries, diminishing returns to reproducible factors do not play an important role anymore as compared to the opportunity to catch up because of technological gaps provided that countries reached what Abramowitz calls a threshold level of "social capability".

3.2.2 "Idea Gaps and Object Gaps in Economic Development" Revisited

A key finding of the "new empirics of economic growth" is the importance of investment in equipment as an exceptional source of economic growth. In seminal contributions, De long and Summers [8] and [9] argue that implied social returns to equipment investment are far above the private returns. However, De Long and Summers [8] also find that this result is not robust to tests for interaction with an income gap variable for high income-countries. As a consequence, they suggest that their high estimate may to some extent reflect catching up. More specifically, they note (p.467-468) that:

> "We find very attractive the idea that a high social product of equipment investment reflects technology transfer mediated through capital goods, and thus that the social product is higher for poorer countries with more of a technology gap to bridge. But the data do not speak reliably enough on this point for us to be willing to do more than point out that the question is intriguing and potentially very important, and the evidence not conclusive."

If De Long and Summers are so cautious in suggesting that their high estimates may indeed reflect technological

[15] NR^2 is equal to 2.56 as compared to the critical value to reject the nested model that is equal to 7.81. Note that a LM-test of a Mankiw, Romer, and Weil specification nested within this more general model leads to a test-statistic equal to 3.53 with a χ^2_2 equal to 5.99.

[16] The adjusted-R^2 is now equal to 0.74 (compare with 0.64 for the MRW specification).

catch up, this is because their results are not robust to sample expansion. In this section, I follow this line of research pioneered by De Long and Summers, and by Romer in his insightful discussion about the relative importance of object gaps and idea gaps. I re-estimate equation (16) but where the absorption capacity of a nation is now approximated by the average share of equipment investment in output as provided by De Long and Summers [9] . Note that the samples under study are similar to that used in the above estimations so that results provided in Table 3 are directly comparable to that obtained in Table 1.

Results from the estimation of equation (16) where the average share of equipment investment in output acts as a proxy for the absorption capability of a country are presented in Table 3 in the column called OIG for Object and Idea Gap model. Note first that the goodness-of-fit criteria are much better that those obtained with the estimations of both the MRW and NP models. Second, the interaction of the initial output per working-age person gap and equipment investment as well as the share of equipment investment in output coefficients fail to be significantly different from zero. This corroborates the finding of De Long and Summers when they consider a large sample of countries. As the conditional number suggests, this may be due to high multicollinearity that again substantially inflates variances of the coefficients. Therefore, a stepwise procedure is applied to the OIG model. The selected model now incorporates only two variables: the share of investment in output enters first followed by the interaction term. The initial output per working-age person does not enter anymore the selected model emphasizing the relative importance of ideas and technology transfer in addition to physical capital accumulation. The conditional number decreases substantially and the fit of this selected model is almost identical to the one corresponding to the more general OIG model. Also interesting is that the size of the coefficient on physical capital investment decreases by almost 15 percent while the coefficient of the interaction term is now twice as large. As the Lagrange Multiplier test cannot reject the selected model as a nested model within the more general OIG model, the relative importance of equipment investment as a factor reflecting technology transfer is now more convincing and can hardly be rejected. The same conclusions can be drawn for the intermediate sample though the stepwise procedure selects first the interaction term and then adds the share of investment in physical capital. Results obtained with the OECD samples are similar to the results obtained

Dependent variable: log difference GDP per working-age person 1960-1985												
Sample	*Non-oil*				*Intermediate*				*OECD*			
Observations	*73*				*65*				*21*			
[a] Model selection	OIG	SOIG	NP	SNP	OIG	SOIG	NP	SNP	OIG	SOIG	NP	SNP
Constant	1.30	0.91	1.60	1.52	1.18	0.85	1.39	1.32	-1.68	0.44	0.20	0.44
	[b](0.24)	(0.00)	(0.09)	(0.08)	(0.30)	(0.00)	(0.15)	(0.13)	(0.36)	(0.00)	(0.88)	(0.00)
ln(Y60)	-0.17		-0.20	-0.19-2	-0.19		-0.21	-0.20-2	0.09		-0.13	
	(0.04)		(0.01)	(0.00)	(0.04)		(0.01)	(0.00)	(0.69)		(0.28)	
(Eq/GDP).ln($Y60_{max}$/Y60)	2.22	4.55-[c]2			1.77	4.45-1			6.83	5.54-1		
	(0.22)	(0.00)			(0.35)	(0.00)			(0.05)	(0.00)		
H3.ln($Y60_{max}$/Y60)			0.61	0.65-3			0.56	0.58-4			1.48	2.05-1
			(0.08)	(0.04)			(0.11)	(0.06)			(0.02)	(0.00)
ln(I/GDP)	0.42	0.36-1	0.59	0.59-1	0.35	0.32-2	0.55	0.55-1	-0.13		0.12	
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.51)		(0.52)	
ln(n+g+δ)	-0.37		-0.53	-0.54-4	-0.44		-0.62	-0.62-3	-0.41		-0.55	
	(0.22)		(0.09)	(0.08)	(0.15)		(0.06)	(0.05)	(0.20)		(0.10)	
Eq/GDP	3.42				4.07				-0.62			
	(0.20)				(0.14)				(0.84)			
H3			0.10				0.07				0.11	
			(0.81)				(0.86)				(0.62)	
d.f.	67	70	67	68	59	62	59	60	15	19	15	19
s.e.	0.289	0.295	0.311	0.309	0.285	0.295	0.312	0.309	0.118	0.116	0.125	0.123
$\overline{R^2}$	0.54	0.52	0.46	0.47	0.48	0.45	0.38	0.39	0.74	0.75	0.71	0.72
[d] κ	6.1	1.5	3.6	2.6	6.0	1.4	3.4	2.4	9.19	1	4.1	1
AIC	31.8	31.9	42.8	40.8	27.4	28.5	38.9	36.9	-24.2	-29.4	-21.8	-26.3
[e] LM-test	5.11		0.06		6.33		0.04		3.77		4.07	

Table 3: Tests for neoclassical convergence and technological catch-up where the absorption capability of a nation is approximated by its equipment investment output ratio and its stock of education at tertiary levels.

Notes:

a. OIG (NP) corresponds to the model as described by equation (16) in the text with the absorption capacity approximated by the equipment investment output ratio (the stock of education at tertiary levels). SOIG (SNP) corresponds to the model nested within the OIG (NP) model and selected by the chosen variable selection method. SW is for stepwise procedure as described in the text.

b. p-values, i.e., the marginal significance level of a two-tailed test of the hypothesis that the coefficient is equal to zero, are in parenthesis under coefficient estimates.

c. In order of the variables added in the model as selected by the stepwise method.

d. κ is the conditional number measuring collinearity.

e. Breusch and Pagan's Lagrange Multiplier test for nested models as described in the text.

in the previous section. The only significant variable is the interaction term whose coefficient is also relatively stable across the different sub-samples though slightly higher for the OECD group. This corroborates De Long and Summers [8] alternative view that equipment investment may indeed accompany technology transfer.

		JA-test		
		Non-oil	*Intermediate*	*OECD*
H0	**H1**			
SOIG	MRW	0.17	0.08	0.84
MRW	SOIG	0.00	0.00	0.02
SNP (H3)	MRW	0.24	0.02	0.16
MRW	SNP (H3)	0.00	0.00	0.02
SOIG	SNP (H3)	0.14	0.22	0.18
SNP (H3)	SOIG	0.00	0.00	0.00
		p-value	p-value	p-value

Table 4: Nonnested hypothesis test: MRW against SOIG and SNP models.

Note: the JA-test performs a test of specification of non nested models as described in the text.

A nonnested hypothesis test of specification is available in Table 4. It provides unambiguous results about which is the preferred model among the competing ones. The selected model where the absorption capability of a country is proxied by its share of equipment investment in output can be specified either as the null hypothesis against the MRW model or as the alternative hypothesis, the outcome remains the same for all three samples. It is always accepted while the MRW model is always rejected with a close to zero probability to be wrong in doing so. This suggests that the MRW model should be either discarded or improved to compete the SOIG model. Recall that the initial output reflecting diminishing returns to reproducible factors does not enter the selected model, this suggests that technology transfer mediated through capital goods yields important opportunities to catch up for poorer countries. Finally, note that catch-up occurs within this selected and preferred model without requiring to control for differences in either human capital accumulation or education stocks.

Table 3 also provides estimations where the absorption capability is proxied by the stock of human capital at tertiary levels. Results are very similar to those obtained when the stock of human capital at secondary levels is considered.

However, the selected nested model within the NP model incorporates the labor force growth rates variable for both the non-oil and intermediate samples of countries. What is important when using education stocks at tertiary levels is that the JA-test always, i.e., for all three samples, rejects the MRW model as the null hypothesis with a close to zero probability of committing a first error type (see, Table 4). Note however, that the SOIG model remains unambiguously preferred to this restricted version nested in the NP model.

4. Counterfactual Income Dynamics and Individual Effects of Diminishing Returns and of Technological Catch-Up

In the MRW model, convergence occurs only because of diminishing returns to reproducible factors and technology is considered as a pure public good. In the SNP model, both the neoclassical convergence effect and the technological catch-up effect are at work. Finally, in the SOIG model, only the technological catch-up effect appears to be significantly important to explain international differences in growth rates, once one controls for differences in physical capital accumulation.

In this section, I propose a non parametric counterfactual exercise that allows us to analyze the individual effects of the various explanatory variables on changes in the world income distribution. It follows Di Nardo, Fortin, and Lemieux [10] who provide an analysis of the effects of institutional and labor market factors on changes in the U.S. distribution of wages. More specifically, they ask (p. 1009): “what would the density of wages have been in 1988 if workers’ attributes, such as their union status, had remained at their 1979 levels?”

Growth regressions as estimated above allow us to calculate the partial contribution of each variable to growth and therefore to quantify the growth rates that would have been observed once differences in all the other variables specified in the empirical model and the fixed effect are controlled for. Therefore it is also possible to calculate what the density of output per working-age person would have been in 1985 if countries had exhibited average behavior in all variables except some variables of interest (see also, De la Fuente who illustrates how traditional cross-country growth regressions can be used to analyze the immediate sources of the income distribution dynamics for a sample of OECD countries though restricting his analysis to the first and second moments of the distribution).

The effects of the different variables are estimated by applying kernel density methods. Thus, the procedure provides a visually clear representation of where in the density of incomes the specified factors exert the greatest impact.

Suppose we are given a sample of independent, identically, distributed realizations of a random variable $\{X_i\}_{i=1}^{n}$. Now, if a smooth kernel function $K\left(\frac{\bullet - X_i}{h}\right)$ is centered around each observation X_i and if we average over these functions in the observations, we obtain the kernel density estimate defined as follows

$$\widehat{f}_h(x) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{\bullet - X_i}{h}\right)$$

The estimate inheritates from all properties of the kernel function, i.e., it is a symmetric probability density function (see for instance, Silverman [20]). Practical application of kernel density estimation is crucially dependent on the choice of the smoothing parameter h. In the following analysis, I use the plug-in method of Sheather and Jones [19] as bandwidth selector that is also chosen by Di Nardo, Fortin, and Lemieux.

A question that originally motivated the convergence literature is: what will the distribution of output per worker look like in the future? In this section, I rather investigate the following question: what the distribution of output per worker would have looked like if countries had been characterized by technological backwardness and different absorbing social capabilities, and by different initial levels of output per worker after having controlled for differences in factor accumulation? This allows us to focus on counterfactual dynamics of the world income distribution implied by the neoclassical convergence effect and the technological catch-up effect. I first estimate the contribution of each variable to the growth performance of each country in the sample given the results obtained from the convergence equations estimated in the previous section. Second, I estimate counterfactual output per worker density estimates that reflect the impact of our variables of interest on the evolution of the income distribution. Such counterfactual income density estimates are plotted in Figure 1. Substantial differences arise between these density estimates and must be explained.

In the upper-left and right plots in Figure 1, I superimpose counterfactual income density estimates that would have been observed at the end of the period under study if countries would have differed only in their initial per worker output as suggested in a Mankiw, Romer and Weil specification (solid lines) and if countries would have been able to benefit from both diminishing returns to reproducible factors and technological gaps as suggested in a Nelson and Phelps' approach (dotted lines), with all countries having displayed average behavior in terms of all other variables. The individual impact on the evolution of the world income distribution of both phenomena can now be clearly seen.

Both density estimates naturally exhibit convergence, but the impact of technological backwardness associated with the absorption capacity of a nation appears to contribute in a larger extent to the decline of the middle-income group and the fattening of the lower tail of the distribution. There is indeed more mass at the bottom of the counterfactual income density estimate implied by the Nelson and Phelps' approach. Although the neoclassical convergence effect appears to affect all countries rather uniformly, it seems that poorer countries do not benefit to the same extent of their technological backwardness compared to countries having already reached a threshold level of development. Their absorption capacity must limit the strength of technological potentiality proper. The counterfactual income density estimate associated with the Nelson and Phelps' approach is to the left of the one associated with the Mankiw, Romer, and Weil's specification for poorer countries. For richer countries though, it is now to the right. This phenomenon becomes even stronger if one looks at the plot in the lower right of Figure 1 where both the convergence effects as specified in equation (16) are distinguishable. The impact of the technological catch-up effect is to yield the middle-income group to vanish: countries belonging initially to this class of income either close their gap with richer countries or fall behind into a poverty trap. Hence, it is, at least partially, responsible for the polarization of the world income distribution into twin peaks, a characteristic of the world income dynamics that has been highlighted, among others, by Quah. This corroborates Abramowitz who argues that only those poorer countries that benefit from a high absorption capability will be able to catch up and to join the group of richer countries. As human capital rises, total factor productivity growth takes place and poorer countries become able to catch up with richer countries. The phenomenon is even stronger when the absorption capacity of a country is proxied by its share of equipment investment in output (see the lower left plot in Figure 1).

Following Di Nardo, Fortin, and Lemieux, I also plot in Figure 2 the difference between the density estimate of the world income distribution in 1985 and each counterfactual density estimated after accounting for the neoclassical convergence effect resulting from the MRW specification (solid line) and from the technological catch-up effect estimated with the SOIG empirical model (dotted line). The closer to the zero line and the flatter is the estimated line, the better the counterfactual density estimate fits the shape of the observed income distribution at the end of the period.

Whatever the class of income is, the impact of the technological catch-up effect estimated with the SOIG model allows for a better fit to the observed income distribution in 1985. Even though, the middle-income group remains too important compared with the one we observed in 1985, the technological catch-up effect clearly yields divergence at the bottom of the income distribution and convergence at the top. There is a clear impact of the technological catch-up effect on the polarization of the world income distribution as advocated by Quah. Recall that the SOIG model could not be rejected while the MRW model was whatever the sample under study, the empirical evidence suggests that indeed differences in technology and in the absorbing capability of a country are crucial determinants of the world income dynamics as opposed to a neoclassical framework where technology is assumed to be a pure public good and where all what matters to explain international differences in growth rates is that countries may suffer from object gaps on the one hand and benefit from diminishing returns to reproducible factors on the other.

5. Conclusion

In this article, I take seriously two alternative theoretical models that have been proposed to explain international growth rates' differences. These differences led to dramatic inequalities in the quality of life that is feasible to the world population. As both approaches have different implications in terms of the development policies and strategies that should be undertaken to lead poorer countries to catch up with richer ones, it is important that growth researchers focus on finding a consensus about the relative importance of the different mechanisms that may offer to poorer countries the opportunity to catch up.

On the one hand, the neoclassical growth theory assumes that technology is a pure public good. International growth rates differences are expected to disappear in the long run because of diminishing returns to reproducible factors. All that poorer countries must do to close their wealth gap is to accumulate more of a capital aggregate that incorporates both physical and human capital. Following Romer's terminology, within a neoclassical framework, poorer countries only suffer from an object gap. This approach is rather pessimistic.

An alternative view argues that technology is less public. Poorer countries also suffer from an idea gap. This yields total factor productivity growth differences to have an impact on the dynamics of the world income distribution. These differences may be permanent or only transitional. In the mid-80s, because growth rates were not converging to similar levels, growth researchers developed models in which technological progress is endogenous. In these models, it is, for instance, argued that capital accumulation leads to technological progress in the form of learning-by-doing that offsets the decline of the marginal productivity of capital. Within this kind of framework, convergence does not occur anymore: the poor stays poor, and the rich stays rich.

However, there is also robust empirical evidence that some poorer countries have been able to catch up while others fell into a poverty trap. The middle-income group vanished over the post World War II period leading to a polarization of the world income distribution. It is, therefore, important to assess whether this convergence phenomenon is the result of diminishing returns to reproducible factors or the result of a technological catch-up effect, or both. Similarly, it is important to know whether the poverty trap arises because of differences in the rates of accumulation, or because countries lack the absorbing capability that would allow them to benefit from their technological backwardness.

To be convincing, the above analysis makes use of formal models and statistical hypothesis tests where both object and idea gaps are allowed to play a role in the evolution of the world income distribution. Hence, it avoids the major shortcoming of the appreciative theory on technology and growth. It aims at finding a consensus about the relative importance of the neoclassical convergence effect and the technological catch-up effect.

The message in this article is the following: the assumption of a common rate of technological progress in a world-wide cross section of countries where all what matters is factor's accumulation is undefensible. The neoclassical growth model provides an incomplete story of growth. And the above empirical evidence emphasizes technology diffusion as a complementary explanation to the worldwide income distribution dynamics. In other words, and as Solow originally argued, both traditional inputs and productivity differences play a large and important role in explaining growth rates differences.

First, robust to sample selection macro empirical evidence suggests that the high social returns to equipment investment may reflect technology transfer mediated through capital goods rather than the presence of externalities taking the form of learning-by-doing.

Second, stocks of education at both the secondary and tertiary levels appear to be also good proxies of the absorption capability of a nation. They play an important role as a determinant of the rate of technological progress by allowing poorer countries to adapt and implement technologies from abroad. All these economic mechanisms better characterize the international growth rates' differences over the period under study than a simple human capital augmented neoclassical growth model does. They cannot be rejected as a null hypothesis.

Third, after having controlled for differences in capital accumulation and the neoclassical convergence effect, technological catch-up mostly benefits those countries endowed with a threshold level of social capability as proxied by its stock of education or its capacity to invest into equipment in which technological change is likely to be embodied, leading therefore to the formation of clubs of economies.

More generally, this should be interpreted as evidence in favor of growth models that emphasize the importance of differences in technology in addition to differences in endowments of human capital to explain international growth rates differences. Some open economy endogenous growth models underline the potential benefits to lagging countries from technology diffusion. The Schumpeterian tradition also strongly supports the view that technology transfer is an important economic mechanism to understand the evolution of the world income distribution. As it is also consistent with the polarization of the world income distribution because technology transfer may encounter obstacles depending for instance on the absorption capacity of a nation, the above macro empirical evidence should lead growth researchers and international institutions like the World Bank to concentrate on working on adapted economic policies that will allow developing countries to successfully adapt and implement new technologies from abroad.

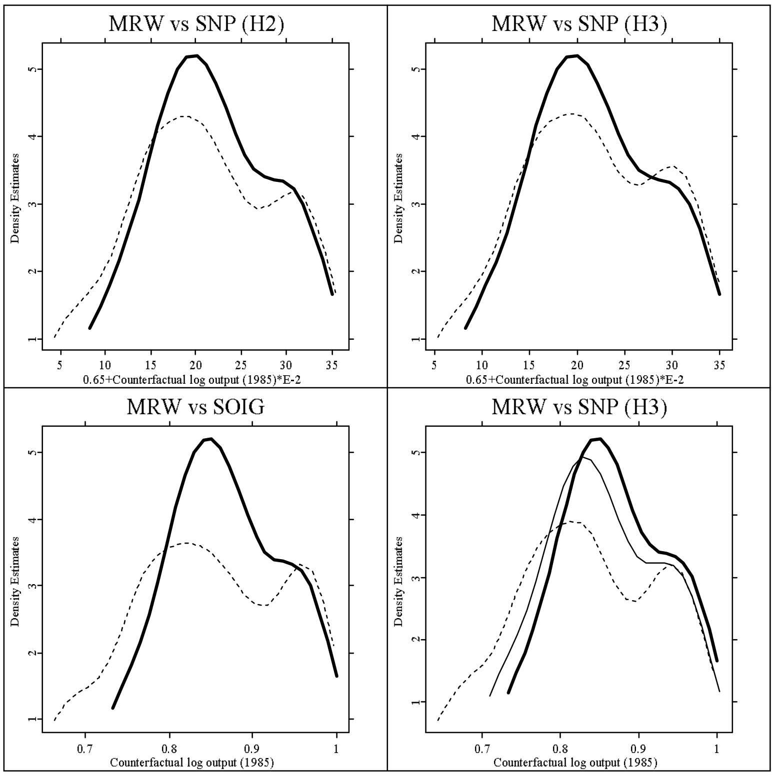

Figure 1: Counterfactual income dynamics: individual contributions of the neoclassical convergence effect as estimated in the MRW model (bold line) and of the convergence effect combining both the neoclassical effect and the technological catch-up effect estimated with the SNP model (dotted lines) where the education stock is measured at secondary levels (left-upper box), and at tertiary levels (right-upper box). In the left-lower box, both the neoclassical convergence effect estimated in the MRW model (bold line) and the technological catch-up effect estimated with the SOIG model (dotted line) are displayed. In the right-lower box, the neoclassical effect (solid line) and the technological catch-up effect (dotted line) estimated with the SNP model where education at tertiary levels acts as a proxy for the absorption capability of a country are displayed, together with the neoclassical convergence effect estimated with the MRW model (bold line).

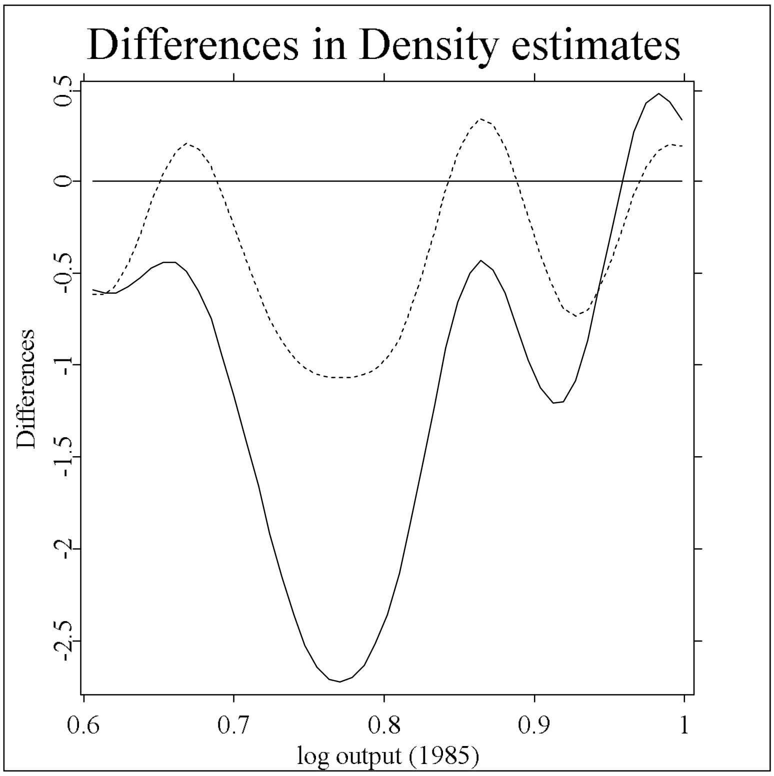

Figure 2: Changes in the world income distribution: differences between the observed density estimate of the log output per working-age person in 1985 and counterfactual density estimates implied by the neoclassical convergence effect in the MRW model (solid line) and the technological catch-up effect in the SOIG model (dotted line).

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